NASA SnowEx Science Plan:

Assessing Approaches for Measuring Water in Earth's Seasonal Snow

Presentation to iSWGR

August 20, 2018

Mike Durand and Mark Raleigh presenting for Science Plan Writing Group: Charles Gatebe, Ed Kim, Noah Molotch, Thomas H. Painter, Melody Sandells, and Carrie Vuyovich

Some Background

- The Terrestrial Hydrology Program 2016 (THP16) funding cycle selected fourteen teams that are assisting in planning SnowEx activities. There are several active THP16 groups, including ours, the Science Plan Writing Group
- The latest Earth Science Decadal Survey (ESDS, released early 2018) is highly relevant. The ESDS supports both
  - A “designated” hyperspectral mission for measuring several targets, including snow cover (SBG) for launch soon (not 100% though)
  - An “explorer” mission for measuring snow depth for launch a bit later
- SnowEx is a NASA-led effort in collaboration and cooperation with international partners in support of a global snow satellite mission concept


UNEDITED PREPUBLICATION—SUBJECT TO FURTHER EDITORIAL CORRECTION

Thriving on Our Changing Planet:
A Decadal Strategy for Earth Observation from Space

Committee on the Decadal Survey for Earth Science and Applications from Space

Space Studies Board

Division on Engineering and Physical Sciences

A Consensus Study Report of
The National Academies of
SCIENCES · ENGINEERING · MEDICINE

THE NATIONAL ACADEMIES PRESS
Washington, D.C.
www.nap.edu

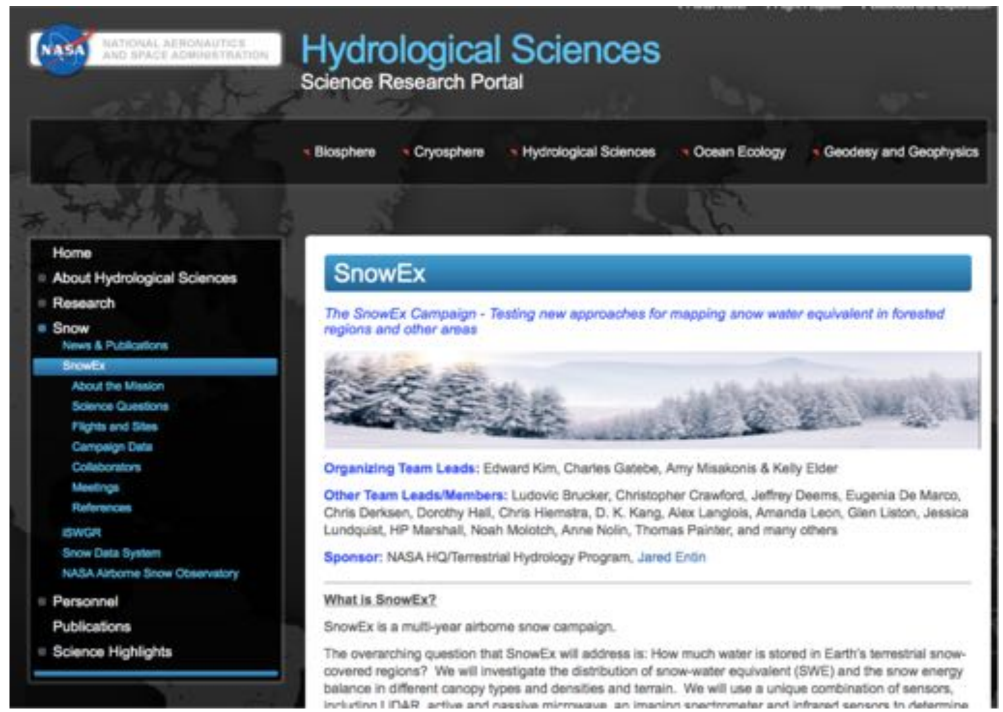
UNEDITED PREPUBLICATION-SUBJECT TO FURTHER EDITORIAL CORRECTION

Science Plan Purpose

- **Purpose**: Support decision making for future (i.e. 2020 and 2021) SnowEx campaigns. Provide guidance to implementation team
- **Scope**: Set priorities; implementation left to implementation team
- **Format**: Charge was received from Jared Entin, THP program manager. Structured around articulating several “gaps”. “Snow in forests” for SnowEx 2017 can serve as an example.
- **Focus**: Where are there opportunities to solve problems, better understand our measurements, models, algorithms etc., and push things forward? Note – clarify SWE, SCA, fractional snow cover
- **Audience**: everyone interested in SnowEx activities. Jared Entin, Jack Kaye, iSWGR, THP16, larger scientific community
- **Status:** This is a living document. We welcome input.

SnowEx is focused on addressing “gaps” in our knowledge of snow remote sensing

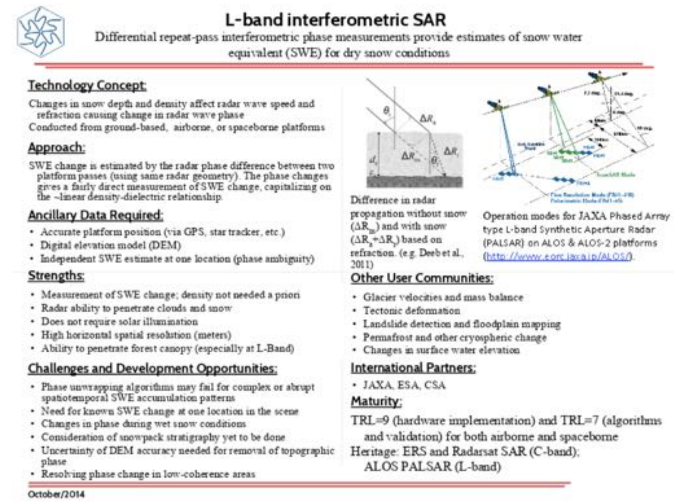
- “Gaps” represent breaks in the continuity of our knowledge of seasonal terrestrial SWE remote sensing techniques that have great relevance for advancing global snow science and, if addressed, could ultimately lead to a spaceborne snow mission concept.
- E.g.: SnowEx 2017 in forests was motivated by the fact that most remote sensing methods struggle to sense snow under forest canopies



https://neptune.gsfc.nasa.gov/hsb/index.php?section=322

Gaps Developed from Quad Charts

- A key component in defining gaps is understanding the available sensing technologies
- The iSWGR community has built a set of 14 quad charts for each sensing method. Two examples are shown at right.
- These were discussed and reviewed at the 2017 Longmont meeting
- Carrie Vuyovich led an exercise to summarize these into a table



L-band interferometric SAR

Differential repeat-pass interferometric phase measurements provide estimates of snow water equivalent (SWE) for dry snow conditions

Technology Concept:

Changes in snow depth and density affect radar wave speed and refraction causing change in radar wave phase

Conducted from ground-based, airborne, or spaceborne platforms

Approach:

SWE change is estimated by the radar phase difference between two platform passes (using same radar geometry). The phase changes gives a fairly direct measurement of SWE change, capitalizing on the ~linear density-dielectric relationship.

Ancillary Data Required:

- Accurate platform position (via GPS, star tracker, etc.)
- Digital elevation model (DEM)
- Independent SWE estimate at one location (phase ambiguity)

Difference in radar propagation without snow (ΔR_{m}) and with snow ($\Delta R_s + \Delta R_i$) based on refraction. (e.g. Deeb et al., 2011)

Operation modes for JAXA Phased Array type L-band Synthetic Aperture Radar (PALSAR) on ALOS & ALOS-2 platforms (http://www.eorc.jaxa.jp/ALOS/).

Strengths:

- Measurement of SWE change; density not needed a priori
- Radar ability to penetrate clouds and snow
- Does not require solar illumination
- High horizontal spatial resolution (meters)
- Ability to penetrate forest canopy (especially at L-Band)

Other User Communities:

- Glacier velocities and mass balance
- Tectonic deformation
- Landslide detection and floodplain mapping
- Permafrost and other cryospheric change
- Changes in surface water elevation

Challenges and Development Opportunities:

- Phase unwrapping algorithms may fail for complex or abrupt spatiotemporal SWE accumulation patterns
- Need for known SWE change at one location in the scene
- Changes in phase during wet snow conditions
- Consideration of snowpack stratigraphy yet to be done
- Uncertainty of DEM accuracy needed for removal of topographic phase
- Resolving phase change in low-coherence areas

International Partners:

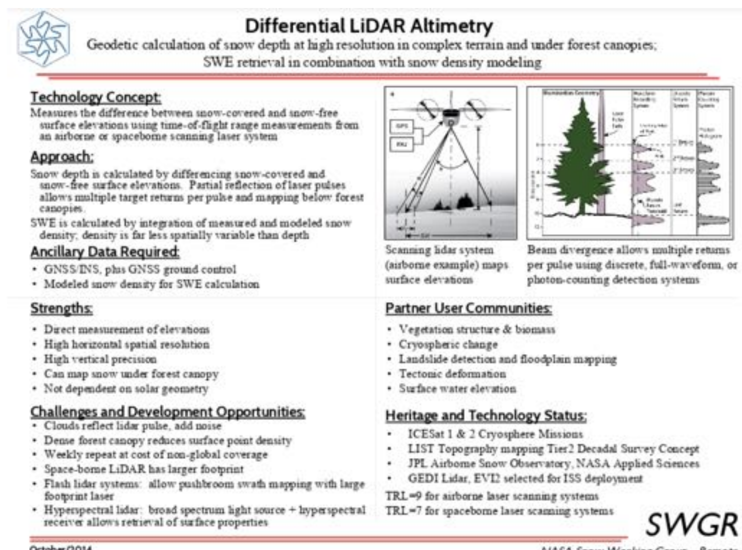
- JAXA, ESA, CSA

Maturity:

TRL=9 (hardware implementation) and TRL=7 (algorithms and validation) for both airborne and spaceborne

Heritage: ERS and Radarsat SAR (C-band); ALOS PALSAR (L-band)

October/2014



Differential LiDAR Altimetry

Geodetic calculation of snow depth at high resolution in complex terrain and under forest canopies; SWE retrieval in combination with snow density modeling

Technology Concept:

Measures the difference between snow-covered and snow-free surface elevations using time-of-flight range measurements from an airborne or spaceborne scanning laser system

Approach:

Snow depth is calculated by differencing snow-covered and snow-free surface elevations. Partial reflection of laser pulses allows multiple target returns per pulse and mapping below forest canopies.

SWE is calculated by integration of measured and modeled snow density; density is far less spatially variable than depth

Ancillary Data Required:

- GNSS/INS, plus GNSS ground control
- Modeled snow density for SWE calculation

Scanning lidar system (airborne example) maps surface elevations

Beam divergence allows multiple returns per pulse using discrete, full-waveform, or photon-counting detection systems

Strengths:

- Direct measurement of elevations
- High horizontal spatial resolution
- High vertical precision
- Can map snow under forest canopy
- Not dependent on solar geometry

Partner User Communities:

- Vegetation structure & biomass
- Cryospheric change
- Landslide detection and floodplain mapping
- Tectonic deformation
- Surface water elevation

Challenges and Development Opportunities:

- Clouds reflect lidar pulse, add noise
- Dense forest canopy reduces surface point density
- Weekly repeat at cost of non-global coverage
- Space-borne LiDAR has larger footprint
- Flash lidar systems: allow pushbroom swath mapping with large footprint laser
- Hyperspectral lidar: broad spectrum light source + hyperspectral receiver allows retrieval of surface properties

Heritage and Technology Status:

- ICESat 1 & 2 Cryosphere Missions
- LIST Topography mapping Tier2 Decadal Survey Concept
- JPL Airborne Snow Observatory, NASA Applied Sciences
- GEDI Lidar, EVI2 selected for ISS deployment

TRL=9 for airborne laser scanning systems

TRL=7 for spaceborne laser scanning systems

October/2014

Quad chart summary table for SWE

Table was populated by consulting quad charts and the literature, and discussing with experts. Some subjectivity is admittedly present.

Table 1. Summary of snow depth/SWE and snow melt estimation techniques

		Snow Characteristic			Gap Capabilities							Space Potential		
Type	Snow sensing/ estimation Technique	Snow Depth	SWE	Melt	High-Res	Wet snow	Deep Snow	Forests	Complex Terrain	Shallow Snow	Clouds	Path to Space	Global coverage	Mature Algorithm
SWE via snow depth	Lidar	Green	Yellow	Red	Green	Green	Green	Yellow	Green	Yellow	Red	Green	Yellow	Green
	Ka-band InSAR	Green	Yellow	Red	Green	Green	Orange	Red	Green	Orange	Orange	Orange	Orange	Orange
	Dual band Ku/Ka	Green	Yellow	Red	Green	Green	Green	Red	Orange	Orange	Green	Orange	Orange	Orange
	Stereo Photogrammetry	Green	Yellow	Red	Green	Green	Green	Orange	Green	Yellow	Red	Green	Yellow	Green
	Wideband Radiometer	Green	Yellow	Red	Orange	Red	Orange	Orange	Orange	Orange	Green	Orange	Orange	Orange
volume scattering	Ku-band SAR	Yellow	Green	Green	Green	Red	Yellow	Orange	Orange	Yellow	Green	Yellow	Yellow	Yellow
	Passive Microwave	Green	Green	Yellow	Orange	Red	Red	Orange	Yellow	Green	Green	Green	Green	Green
signal interferom.	L-Band InSAR	Yellow	Green	Green	Green	Red	Yellow	Orange	Orange	Yellow	Green	Green	Yellow	Yellow
	Signals of Opportunity	Yellow	Yellow	Red	Orange	Yellow	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange
airborne / ground only	FMCW Radar	Green	Green	Red	Green	Yellow	Green	Orange	Orange	Green	Green	Red	Red	Orange
	Gamma	Yellow	Green	Red	Yellow	Green	Yellow	Yellow	Yellow	Yellow	Green	Red	Red	Green

Green – Demonstrated capability. May not work in all areas, but uncertainty is understood. May still benefit from additional research and algorithm development. TRL > 5?
Yellow – Potential capability identified and validated in multiple studies. Research needed to better quantify uncertainty. TRL 3-5?
Orange – Potential capability identified, but uncertainty not quantified. High risk. TRL 1-2?
Red – No Capability

Process for defining gaps

- We “reverse engineered” a one-page description of the “gap” addressed by SnowEx 2017 related to forest sensing of snow
- Members of the writing group led efforts to define six additional gaps. We presented this list of seven gaps to the rest of the THP16 group (July 9).
- We then discussed each gap with experts on snow sensors, as time permitted. We’d love more input if you would like to provide it by email (see final slide)!
- Gaps do not have to refer to a single type of snow, and can overlap with other gaps, as long as there is an important science angle, and a unique measurement challenge
- This process is admittedly somewhat unorthodox; some members of the writing group felt we ought to follow a more rigid STM-type process.

Seven gaps for SnowEx to address

- The final list includes:
  - Forest Snow
  - Maritime Snow
  - Mountain Snow
  - Prairie Snow
  - Snow Surface Energetics
  - Tundra Snow
  - Wet Snow
- We found explicit prioritization of these to be a challenge. We focused on clustering them, and seeing which might be addressed with SnowEx activities

Addressing gaps with SnowEx activities

- 2016-2017 addressed snow in **forests**
- 2018-2019 will address **mountain** snow and **wet** snow
- 2019-2020 will be joint with the ABoVE campaign. We hope it can address high-latitude forests and **tundra** snow
- 2021 (possible) would focus on either **prairie** snow, or on **maritime** snow, or potentially address both of them. Dependent on resources.
- SnowEx resources should be dedicated to address **energetics** modeling, and data assimilation in each campaign
- Thus, it is potentially possible that all gaps may be addressed, subject to resource availability

Science questions and science traceability matrix (STM)

- **SnowEx Overarching Question:** What is the distribution of snow-water equivalent (SWE), and the snow energy balance, in different canopy types and densities, and terrain?
  - *Originally articulated for SnowEx 2017, and revised during spring 2018 in planning for future SnowEx campaigns (working group led by Jeff Deems) and other gaps (e.g., boreal forests, gradients in topography)*

- Science traceability matrix (STM) starts with overarching question, and moves to “fundamental questions”, mission objectives and ancillary questions and measurement requirements.
  - Bifocal approach: STM was focused on SnowEx 2018-2019, but many aspects relevant to other years of SnowEx.

Status, and things still to be done

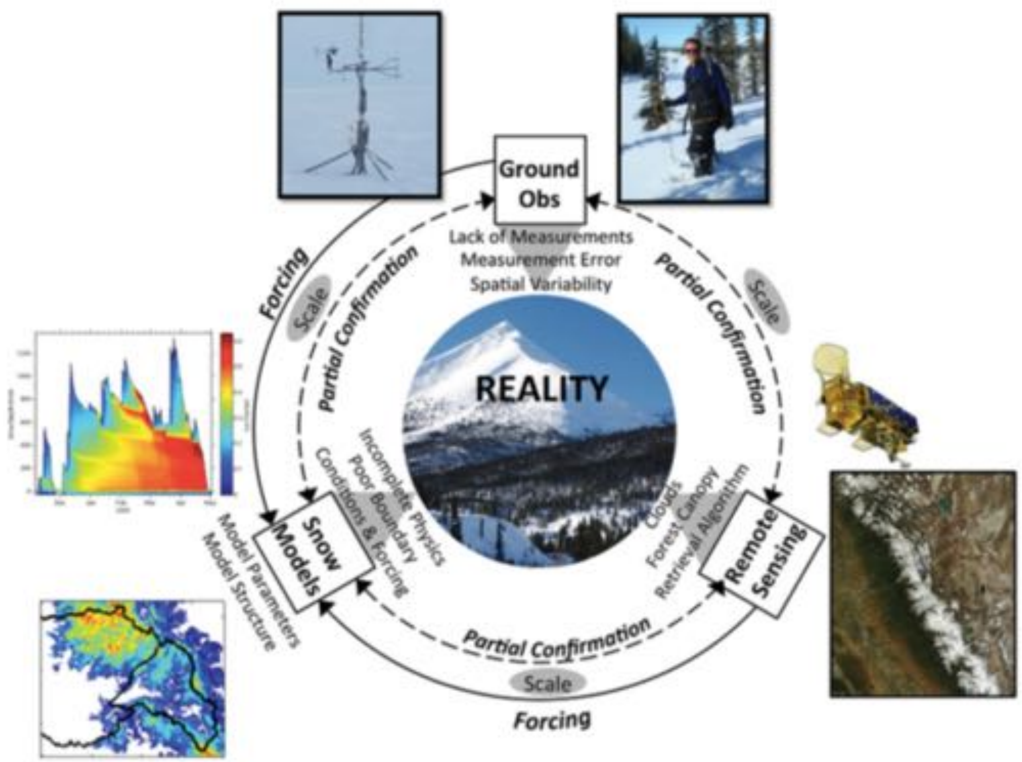
- We are continuing to receive feedback: from the THP16 group, from THP program manager, and hopefully from you!
- Some things remain to be done; reference completion in progress, e.g., and additional graphics would improve the document.
- Other pieces would be good to add as possible, e.g. more information on challenges of spaceborne lidar remote sensing of snow

NASA SnowEx Science Plan:

Assessing Approaches for Measuring Water in Earth's Seasonal Snow

Conclusion & Recommendations

- The SnowEx science plan articulates seven gaps to address
- We must continue to work collaboratively with international efforts (e.g. Trail Valley Creek, tundra snow, Environment Canada 2018-2019, and Chinese WCOM efforts)
- A major recommendation is to continue to focus on modeling and data assimilation to bring the various technologies together (at right)
- Snow Ensemble Uncertainty Project activities should better inform prioritization (Vuyovich, Houser, and others)
- Quad charts, and science questions should be revisited



Sturm, Water Resources Research, 2015.

Your input is welcome!

- Please read the Science Plan. We are currently at v1.5. It is available here (Google Doc) here: https://goo.gl/sFkxHc
- We would love to receive feedback by August 31. Please address any feedback to: Mike Durand (durand.8@osu.edu) and Mark Raleigh (mark.raleigh@colorado.edu)